Habitat Features and Aquatic Health: Evaluating California's Stream Bioassessment Procedure in Natural and Artificial Streams in a Grazed Eastern Sierra Valley

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Abstract

The objectives of this project were to: 1) assess the biotic integrity of benthic macroinvertebrate communities in 7 stream systems subjected to grazing and irrigation within Bridgeport Valley using the California Stream Bioassessment Protocol (CSBP); 2) determine if yearly variation exists for standard macroinvertebrate metrics; and 3) identify correlations between CSBP visual habitat quality assessment, macroinvertebrate community, and habitat features. Thirty 100 m study reaches were established across the 7 stream systems, representing the range of habitat type and quality found in Bridgeport Valley. In August 1999, macroinvertebrate collections, visual habitat quality assessments, and habitat feature measurements were conducted across 3 riffles within each of the 30 (n=90) study reaches according to the CSBP protocol. Macroinvertebrate collections were repeated during August of 2000 at 14 study reaches (n=42) to evaluate inter-annual variability in key CSBP macroinvertebrate metrics. Macroinvertebrate collections were sub-sampled, and all sub-sampled individuals were identified to family. Overall, biotic integrity of streams in Bridgeport Valley is relatively high (CSBP mean habitat quality assessments of "optimal" and "sub-optimal"; 69% EPT taxa), but CSBP habitat quality assessments indicate there is room for improvement across the Valley. Annual variation in macroinvertebrate community requires that comparisons across streams must occur within the same year, and that multiple years of data collection is justified. CSBP habitat quality visual assessment scores and habitat features were weakly correlated to aquatic macroinvertebrate community. While weak, these relationships did generally respond as expected from published work. We found the CSBP habitat quality assessment worksheet to be a valuable tool allowing trained individuals to identify relatively high and low habitat quality within managed systems. However, we must question the value of macroinvertebrate metrics as indicators of variable levels of grazing and irrigation impact on habitat quality typical of the eastern Sierra Nevada.

Introduction and Problem Statement

This research explores a central question in the application of rapid benthic maroinvertbrate-based assessment procedures to eastern Sierra Nevada stream systems: to what extent do habitat features and visual assessment of habitat quality correlate with macroinvertebrate community. Once validated regionally, rapid bioassessment methods can serve as simple, inexpensive tools to assess land use impacts on in-stream habitat and aquatic life, providing important feed-back to land managers.

Karr (1981) is widely credited with having introduced the first "Index of Biotic Integrity (IBI)" which used fish as indicator organisms, evaluating a single sample from the target stream according to twelve attributes or “metrics,” e.g. non-native species, tolerant species, piscivorous species, etc. The system was fast, simple and cheap, and moreover, it worked well: in one case, for example, changes in the IBI revealed problems with temperature and flow regimes that spot sampling missed (Fore et al, 1995). Nonetheless, fish-based indices were more suitable in the East than in the West. In mountainous regions, many pristine rivers and lakes have no fish at all, while at lower elevations, fish stocking programs have altered species compositions. Almost all streams, however, have macroinvertebrates, and so, by the late 1980s, there was a widespread trend away from fish and towards macroinvertebrate-based indices (Resh et al, 1995). In 1989, the USEPA unveiled its Rapid Bioassessment Protocol III (Plafkin et al., 1989). The RPB III is indeed “rapid”: it uses a sample of only 100 invertebrates taken from a riffle/run habitat and coarse particulate organic matter (e.g. leaf pack) to make its assessment. Not surprising, many water resource managers have questioned its value, and it has been under revision almost since its introduction (Hannaford and Resh, 1995).

The California Stream Bioassessment Procedure (CDF&G, 1998a) is a regional adaptation of the RBP III. The basic approach has been used by the California Department of Fish and Game aquatic biologists for some years. The CSBP attempts to address a number of the issues raised about RBP III. First, CSBP explicitly requires a standardized habitat assessment for each site. One of the problems with biotic indices is the dearth of information linking macroinvertebrate communities with habitat type: by requiring habitat assessments, CSBP allows for testing of correlations between habitat type, quality and macroinvertebrate community. Second, CSBP departs from the practice of taking a single grab sample in a riffle. Instead, it requires at least three samples across each transect and allows for more than one transect per riffle. Finally, it uses metrics, which have proven themselves in the Pacific Northwest in the past, such as total number of taxa and percent EPT.

Objectives

The specific objectives of this project were to: 1) assess the biotic integrity of benthic macroinvertebrate communities in seven tributary stream systems subjected to grazing and irrigation within Bridgeport Valley above Bridgeport Reservoir using CSBP; 2) determine if year effects exist for standard macroinvertebrate metrics used in CSBP; and 3) determine whether any correlations exist between CSBP habitat visual assessment score, standard macroinvertebrate community metrics, and measured habitat features.

Experimental Procedures

Study Site

The research was conducted during the summers of 1999 and 2000 in Bridgeport Valley above Bridgeport Reservoir. Bridgeport Valley is an ~25 mi^2 irrigated, grazed wetland on the eastern slope of the Sierra Nevada Mountains. Historically part of a sagebrush steppe dominated by shrub communities, Bridgeport Valley now supports widespread aquatic plant species due to historic and current flood irrigation practices. Approximately 8,000 cattle are grazed in the Valley during summer months. There are 7 tributary stream systems draining into Bridgeport Valley, all subject to the effects of grazing and irrigation practices to varying levels. Each stream system includes both natural stream channels as well as artificial channels in the form of irrigation water delivery and return flow ditches. Most of these artificial channels are 100+ years old and in some cases provide high quality aquatic habitat. We chose this site because it represents an unusual opportunity to sample a number of stream systems that have the same overall climatic, geological, geographical and vegetation contexts; but which differ markedly in key habitat features. A total of 30, 100 m study reaches were established across the 7 stream systems representing the range of habitat type and quality found in the Valley.

Field Data Collection

In August 1999, macroinvertebrate collections, visual habitat quality assessments, and habitat feature measurements were conducted across 3 riffle-transects within each of the 30 (n=90) study reaches according to the CSBP protocol (CDF&G, 1998a). Macroinvertebrate collections were repeated during August of 2000 at 14 study reaches (n=42) to evaluate inter-annual variability in key CSBP macroinvertebrate metrics. Macroinvertebrate collections were made with a D-ring kick net by disturbing a 1 by 2 ft area of substrate upstream of the net for 2 minutes. Collections were immediately stabilized with 95% ethanol. Habitat quality at each collection site was visually assessed and scored using the CSBP ranking system (0 through 20; where 0-5 is poor, 6-10 is marginal, 11-15 is sub-optimal, and 16-20 is optimal) for the 10 habitat features examined within CSBP (Table 1). The following habitat features were physically measured at the time of sample collection following CDF&G protocols (1998b); temperature, dissolved oxygen, stream width, water depth, velocity, % canopy, substrate score, embeddedness, % fines, % gravel, % cobble, % boulder, % bedrock, and periphyton.

Macroinvertebrate Identification and Metrics

A total of 100+ macroinvertebrates per collection (3 riffle collections sites per study reach) were sub-sampled following CSBP protocols, such that a total of 300+ individuals were sub-sampled per study reach. Every macroinvertebrate in each sub-sample was identified to the family level following Merritt & Cummins (1996). For this report, the CSBP macroinvertebrate metrics reported in Table 2 were calculated for each collection site and are reported upon. Additional metrics will be analyzed and results reported in future publications.

Data Analysis

Year effect (1999 and 2000) on macroinvertebrate metrics from 2 stream systems (1 and 3) was tested for using ANOVA with stream, year, and stream x year interaction in the model as factors. Simple correlation analysis and stepwise linear regression were used to determine the strength and direction of relationships between CSBP visual habitat quality assessment score, macroinvertebrate metrics, and measured habitat features.

Results

Biotic Integrity in Bridgeport Valley Stream Systems

CSBP assesses the biological integrity of a stream reach, or system, via a simple visual assessment of the quality of 10 key habitat features (Table 1) as well as via standard macroinvertebrate metrics (Table 2). Figure 1 reports the mean CSBP habitat quality score for each of the 7 stream systems used in this study. Three streams scored “optimal” and the remaining 4 scored “sub-optimal”. The lowest score was an 11, at the bottom of the “sub-optimal” category. Figures 2 and 3 illustrate the values of macroinvertebrate metrics for each stream system. % EPT ranged from 53 to 82% with an overall mean of 69% in 1999. EPT taxa, commonly called mayflies, stoneflies, and caddesflies, acquire dissolved oxygen through external gills or by cutaneous respiration and therefore require low sediment levels and adequate oxygen levels. These taxa are considered to be very sensitive to water quality impairment by land use, and a high percentage of EPT taxa is indicative of favorable water quality and aquatic habitat conditions. While there is significant variability in CSBP habitat quality score and metrics across stream systems, the overall biotic integrity of streams in Bridgeport Valley is relatively high. Figure 4 illustrates the variability in biotic integrity realized across the entire 30 study reaches used in 1999, as well as the fact that there are reaches of stream within the Valley with room for habitat improvement. The reaches with lower scores are sites with relatively heavy grazing and irrigation management impacts. Reaches with higher scores are associated with relatively light grazing and irrigation impacts. These results indicate the value of CSBP habitat quality assessments to provide feedback to managers on management and habitat interactions.

Year Effects on Macroinvertebrate Metrics

Table 3 reports the results of ANOVA for stream systems 1 and 3 with stream, year, and stream x year interaction as factors and macroinvertebrate metric as the dependent variable. Figures 5 and 6 illustrate the mean values of metrics evaluated in this analysis. There was a significant ($p<0.05$) stream effect for all metrics except No. EPT taxa and % Dominant Taxa . Significant stream effects were expected given the inherent differences in flow and temperature regime for streams 1 and 3.

Year was significant for % EPT and % Ephemeroptera, and there was a significant year by stream interaction for No. EPT taxa, No. Plecoptera, and No. Total Taxa. The influence of year on 5 out of 10 key metrics indicates that care must be taken when comparing the integrity of a single stream or multiple streams between years based upon macroinvertebrate metrics. Our results show that valid evaluations of land use impacts via this method must account for possible inherent yearly variation in macroinvertebrate metrics.

Correlating Habitat Type, Quality, and Macroinvertebrate Community

Table 4 reports the Pearson’s correlation coefficients for CSBP visual habitat quality score (see Table 1) by macroinvertebrate metric. Few strong (>0.5) correlations between these factors are revealed in this analysis. With a few exceptions the direction of the relationships between each metric and habitat quality assessment are as expected (i.e. + or -) for all metrics with the exception of % Baetidea, which responds positively to improving habitat quality when one would expect it to respond negatively. Figures 7 and 8 illustrate the results of simple linear regression predicting % EPT and No. Taxa by mean CSBP habitat quality score, and further indicate the weak relationship of standard macroinvertebrate metrics to habitat quality as visually assessed in CSBP. This poor relationship indicates that CSBP habitat quality assessments are not strong predictors of macroinvertebrate community, and visa versa, in these grazed and irrigated systems.

One might question the value of the mean CSBP habitat quality score as the best synthesis of information provided from the 10 CSBP habitat quality assessments conducted per site. We conducted step-wise linear regression analysis with all 10 CSBP habitat feature quality scores as independent variables in original models predicting % EPT and No. Taxa. Compared to Figure 7 and 8, much improved relationships between CSBP habitat quality assessments and macroinvertebrate metrics were developed in this manner. The final model for % EPT = 9.2 + 4.9(CSBP2) -2.7(CSBP3) + 2.0(CSBP8) – 5.4(CSBP9) + 4.6(CSBP10); $R^2 = 0.20$, $p<0.001$ and the final model for No. Taxa = 0.6 + 0.5(CSBP2) + 0.3(CSBP4) - 0.3(CSBP5) + 0.2(CSBP6); $R^2 = 0.26$, $p<0.001$. The methods by which the results of the CSBP habitat quality assessment are synthesized to develop an overall score need to be examined in more detail. This is a short-coming of all existing qualitative, and most quantitative, stream health assessment methodologies.

Table 5 reports the Pearson's correlation coefficients for macroinvertebrate metric by measured habitat parameters. Again, there are few strong correlations identified in this analysis. While the correlations are weak (<0.5), the direction of most relationships is as would be expected particularly for temperature, periphyton, % gravel, % canopy, water depth, substrate. For instance, the % EPT is negatively correlated to stream temperature (-0.36) and periphyton (-0.32) indicating that the % EPT will decrease as stream temperature and periphyton increase with water quality impairment. However, there are some unexpected relationships. % EPT is negatively correlated with dissolved oxygen (-0.20), the exact opposite of what would be expected. As discussed earlier, there is limited information available on the relationships between specific macroinvertebrate communities and habitat features. It is not surprising that macroinvertebrate community cannot be predicted by simple habitat features. One would expect macroinvertebrate community to be determined by complex and interacting combinations of physical, chemical, and biological factors operating through time and space. We will continue to examine our data in an attempt to identify some of these combinations.

However, the analysis reported in Table 4 and 5 does raise the question of how reliable macroinvertebrate communities are as predictors of specific habitat quality or degradation in variably grazed, irrigated stream systems typical of the eastern Sierra Nevada. For instance, an increase in embeddedness and % fines is often associated with a reduction in habitat quality resulting from excessive erosion and sedimentation within the watershed. Thus, in order for macroinvertebrates to be a good indicator of water quality impairment, one would expect several metrics to be strongly correlated (+ or -) to embeddedness and or % fines. Examination of Table 5 indicates that this is not the case for our data from Bridgeport Valley. One possible explanation is the range of embeddedness and %fines found within our study reaches and throughout Bridgeport Valley. While we did capture the range of habitat quality found throughout Bridgeport Valley, it is a relatively narrow range when compared to that for which these metric were developed on a National scale. Continued work will be required to identify metrics which are sensitive to the scale of habitat quality typical of the region.

Table 6 reports the Pearson's correlation coefficients for CSBP habitat quality score by measured habitat parameters. While there are again no strong correlations, the relationships are as expected. Temperature, periphyton, % gravel, substrate, % boulder, % canopy, stream width and depth are habitat features which are fairly well correlated to visual habitat quality score. These results are in agreement with companion work we are conducting to correlate overall in-stream habitat quality with inherent stream characteristics as categorized by Rosgen stream type. We have found that Rosgen A and B type streams (boulder / cobble substrate, high gradient) inherently have higher habitat quality scores when compared to Rosgen C and E (gravel / fine substrate, low gradient) stream types (Ward et al., 2001). While CSBP does account for high v. low gradient streams, care must be taken when comparing streams with inherently different substrate and gradient, and thus habitat quality as estimated by CSBP.

Conclusions

While the overall biotic integrity of streams in Bridgeport Valley is relatively high, there are stream reaches with room for habitat improvement, particularly those subject to relatively heavy grazing pressure and/or the cumulative effects of irrigation management. Overall, the CSBP habitat quality assessment represents a valuable tool allowing trained managers to identify relatively high and low quality stream reaches, efficiently focusing management activities designed to improve aquatic habitat. We found significant year effects on several macroinvertebrate metrics, indicating that at a minimum valid comparisons across streams must occur within the same year, and that multiple years of data collection is likely justified prior to forming strong conclusions. We found CSBP habitat quality visual assessment scores and measured habitat features to be weakly correlated to aquatic macroinvertebrate community metrics; raising the question of how reliable macroinvertebrate community is as a predictor of specific habitat quality or degradation in variably grazed, irrigated stream systems typical of the eastern Sierra Nevada. Continued work will be required to identify metrics which are sensitive to degradation within the scale of habitat quality typical of the region.

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